Jet Propulsion Laboratory
California Institute of Technology

Overview of the Deep Space Network

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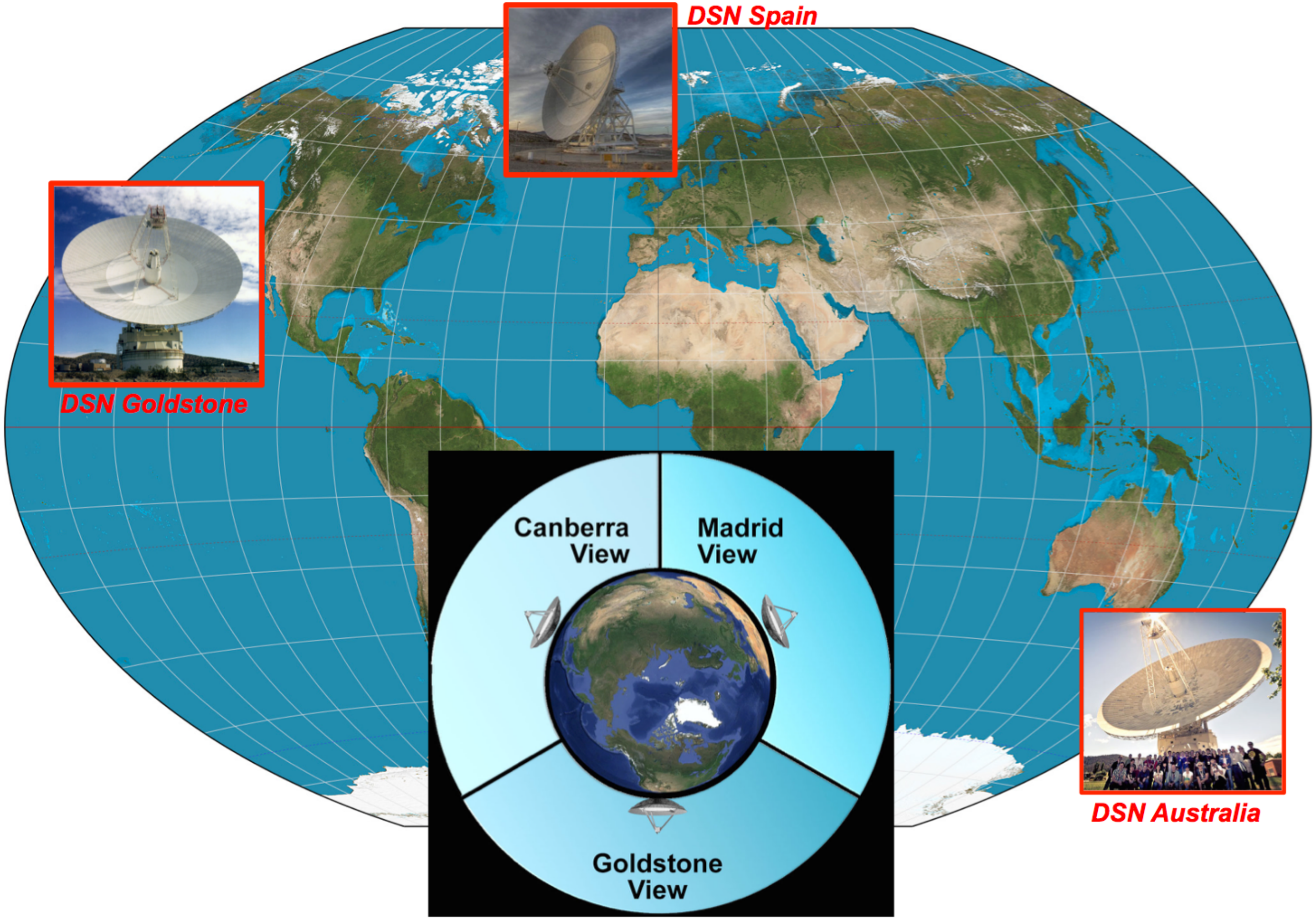
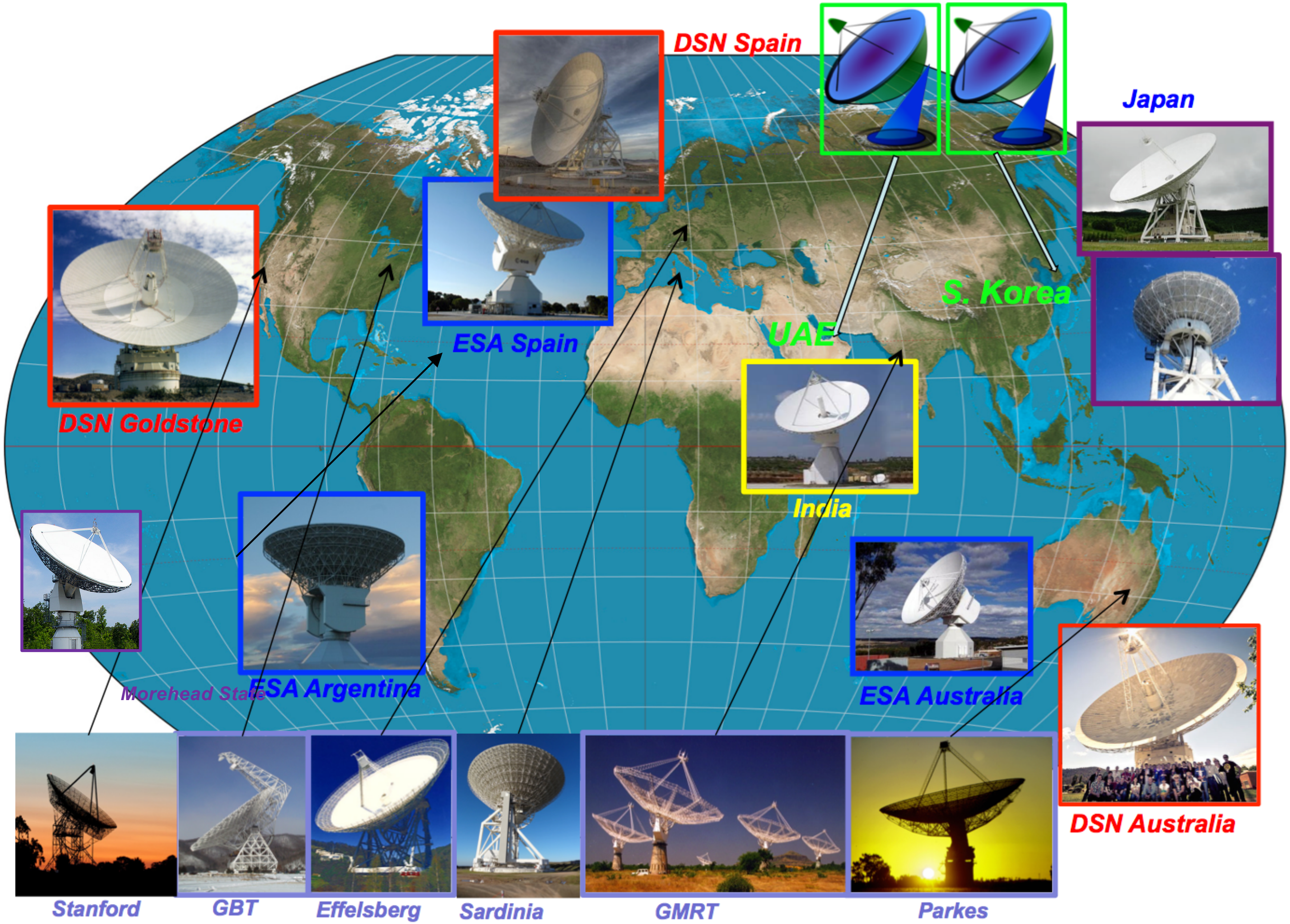
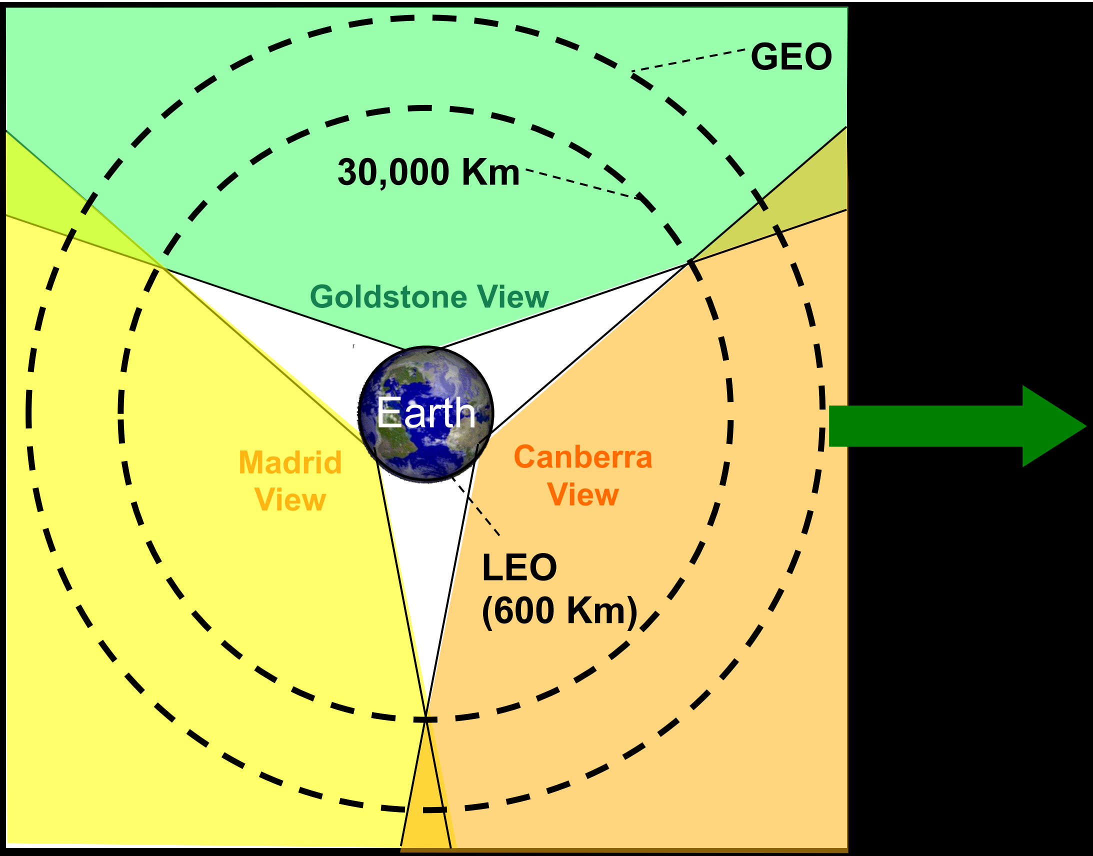

DSN Spain
DSN Goldstone
DSN Australia
Canberra View
Madrid View
Goldstone View


DSN Spain
Japan
DSN Goldstone
ESA Spain
S. Korea
UAE
India
ESA Argentina
Morehead State
ESA Australia
DSN Australia
Stanford
GBT
Effelsberg
Sardinia
GMRT
Parkes

A Global Enterprise by Necessity

GEO: Geostationary

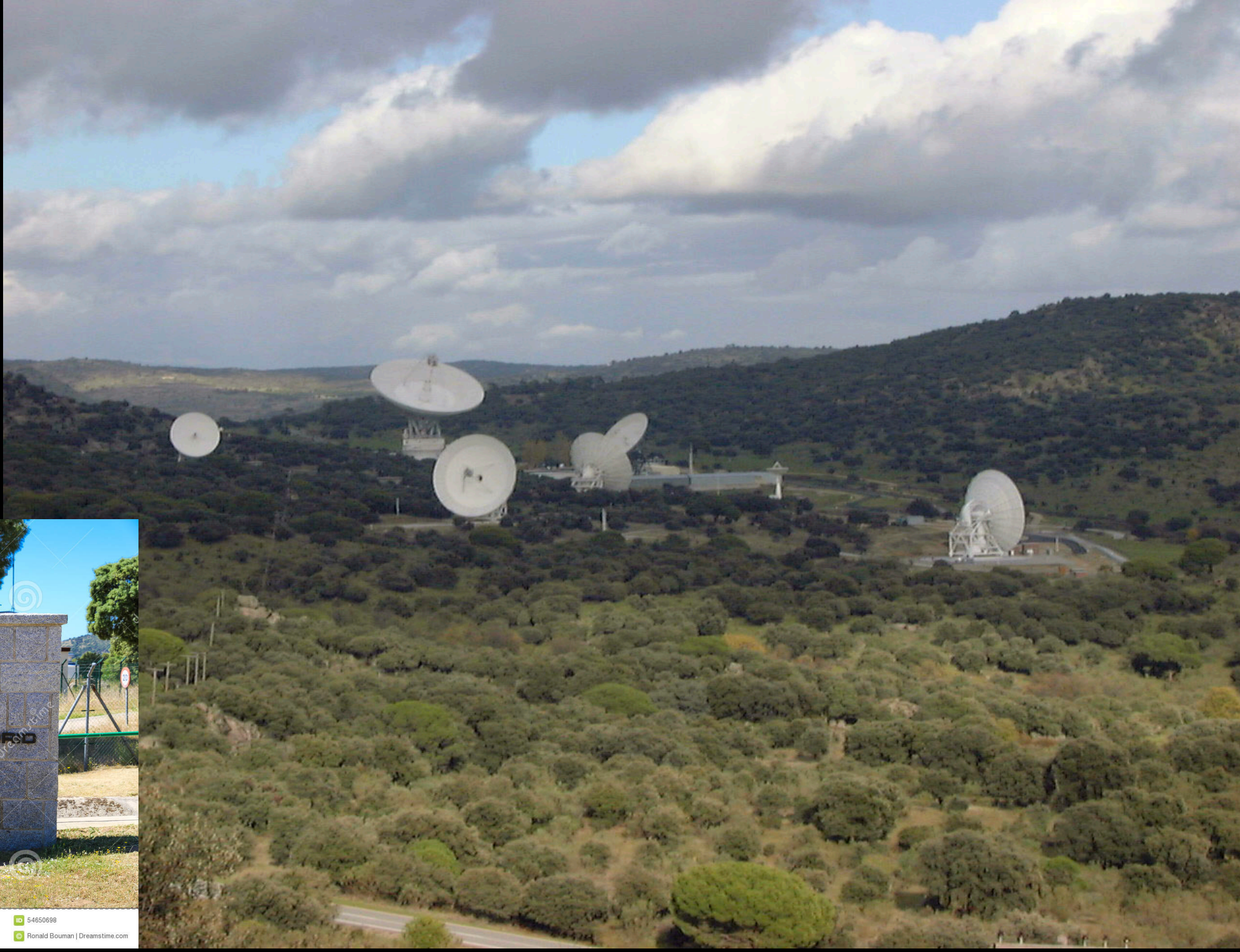
LEO: Low Earth Orbit



Moon is thataway at 10x GEO

DSN Antennas in Canberra, Australia

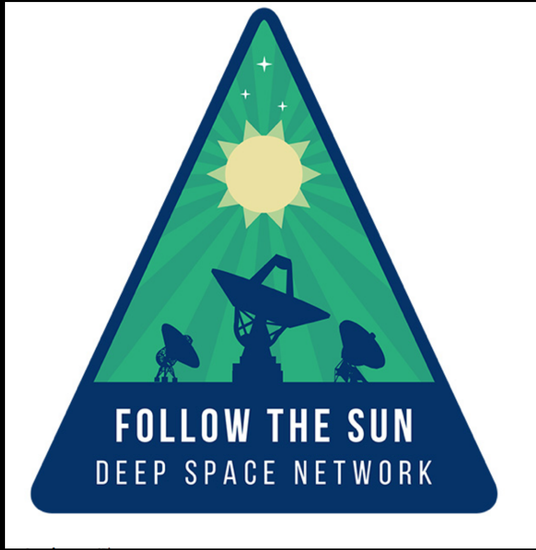
DSN Antennas in Madrid, Spain



DSN Antennas in Goldstone, California

DSN Operations

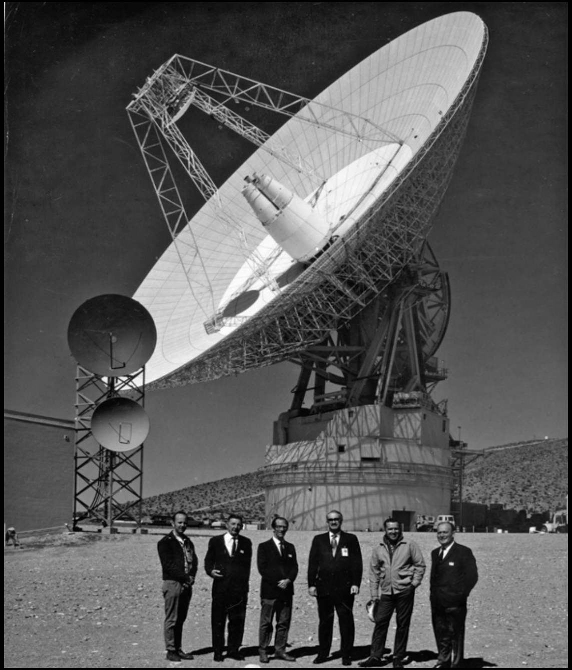
- Operate from all three sites and JPL “darkroom”
- Use follow-the-sun operational paradigm at Goldstone, Canberra and Madrid with day-shifts to cover 24x7
- Multiple tracking passes per operator
- Multiple spacecraft per antenna, in the same beam width
- Remote Operations Center for critical events
- Emergency Operations Center for continuity
- Monthly statistics
  - ~39 missions
  - ~1755 contacts
  - ~7,860 project hours
  - 99.2% telemetry, command and tracking data delivery



History of Ground Antennas

1958, 26m Station

1979, 34m Station

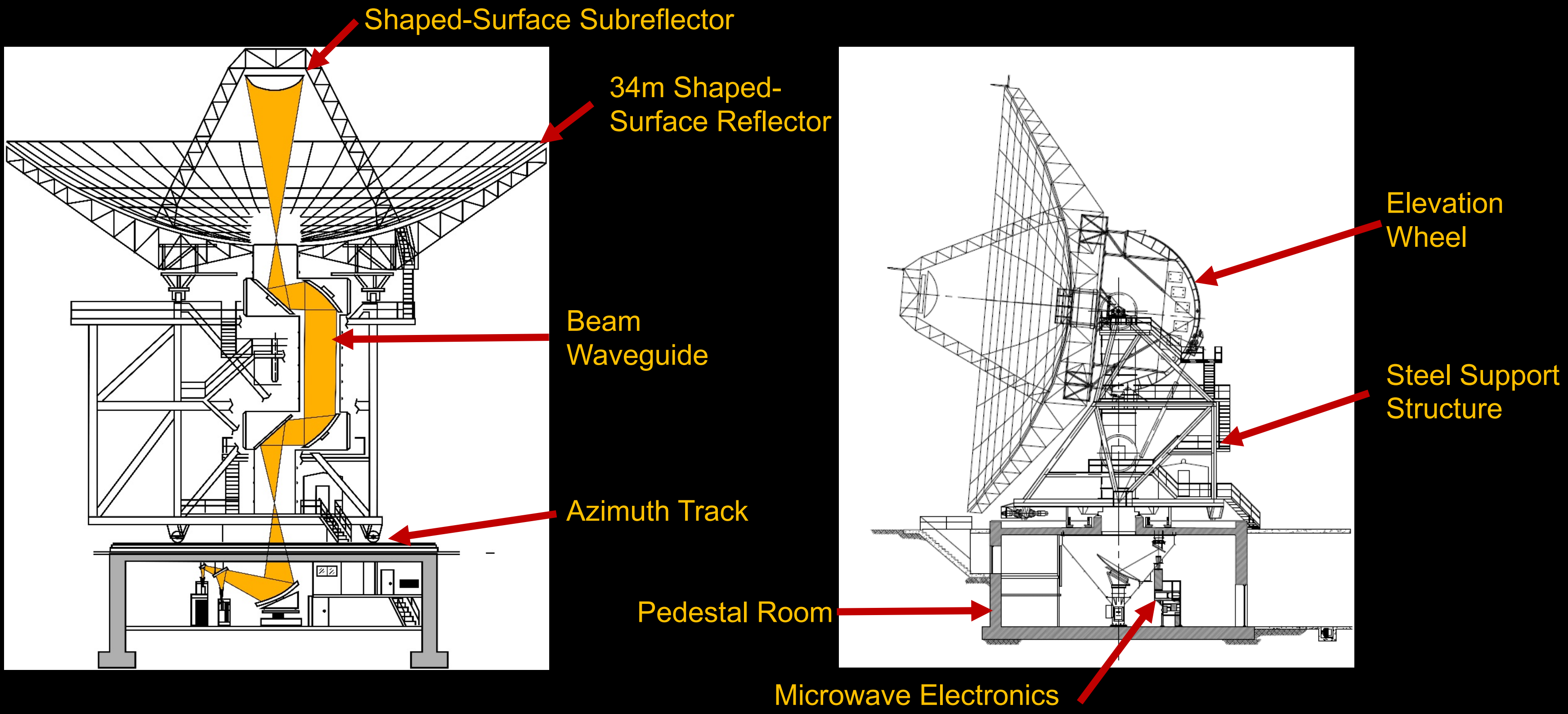


1966, 64m Station

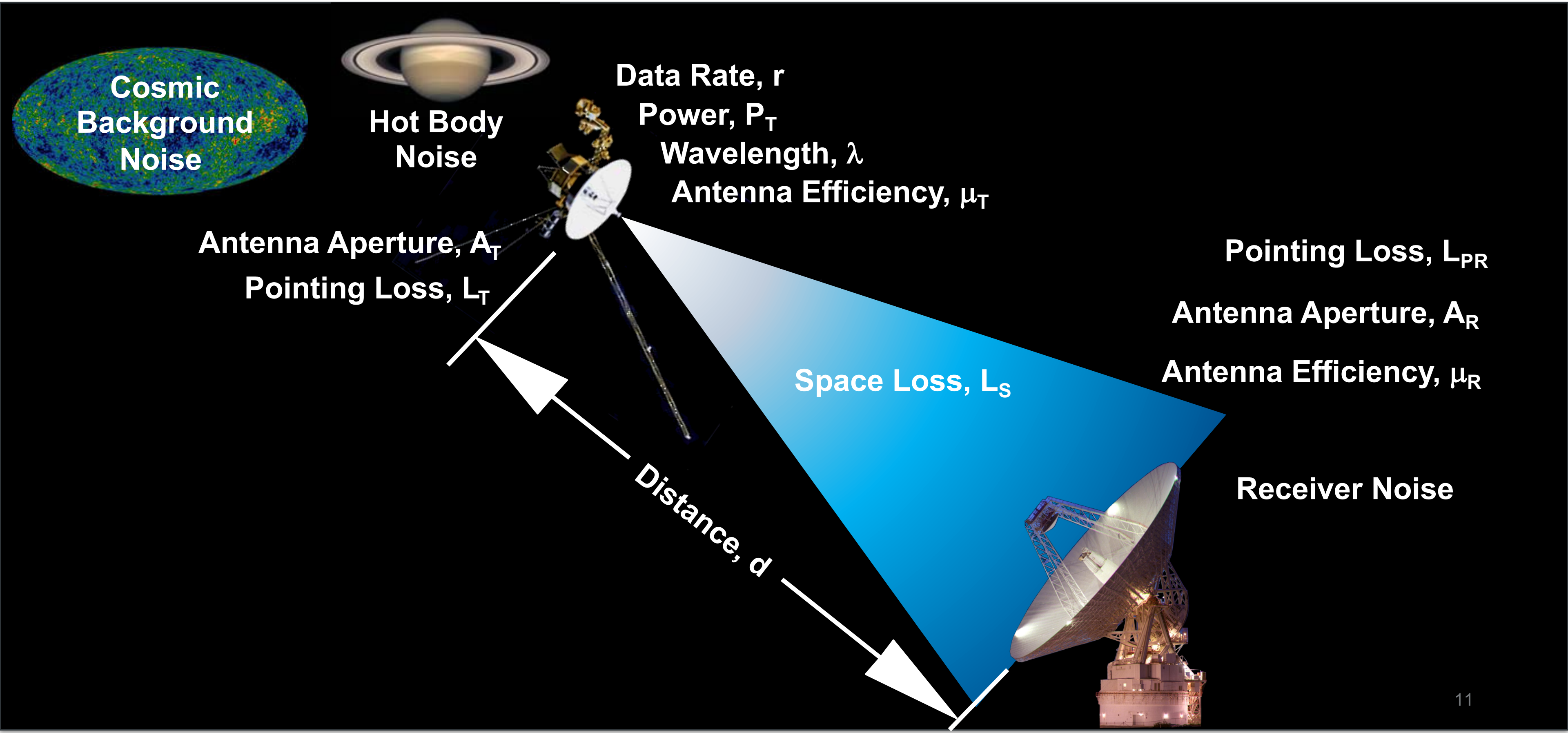
1988, 70m Station

Modern Work Horse

DSN 34m Beam Waveguide Antenna



Deep Space Communications



Why Deep Space Communications is Hard

$E_b/N_0 = \text{constant} / d^2$

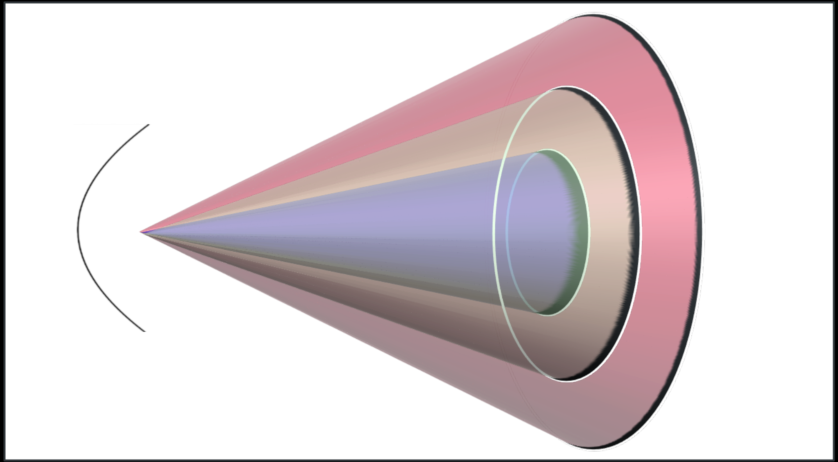
Relative Difficulty

Place	*Distance*	*Difficulty*
GEO	*4×10^4 km*	*Baseline*
Moon	*4×10^5 km*	*100*
Mars	*3×10^8 km*	*5.6×10^7*
Jupiter	*8×10^8 km*	*4.0×10^8*
Pluto	*5×10^9 km*	*1.6×10^{10}*

Higher Frequency is Good

$$E_b/N_0 = \text{constant} * f^{\,2}$$

- Fist deep space missions transmitted at 960 MHz
- 2.2 GHz (S-band) became standard in 1969
- 8.4 GHz (X-band) became prevalent in the early 1970s
- 32 GHz (Ka-band) is now becoming the standard



Lowering the System Noise

$$E_b/N_0 = \text{constant}/T$$

- Some of T cannot be controlled
- Focus on spacecraft & DSN contributions
- Avoid interference
  - Our own spectrum from the ITU
- Best low noise amplifiers we can
  - Physical temperature is ~12 K

Ka-band (32 GHz) low noise amplifier

Error Detecting and Correcting Codes

- Error Detecting and Correcting Codes have a long history in the DSN to improve the quality of the delivered data
- DSN supports Reed-Solomon, Convolutional, Turbo, Low-Density Parity Codes or a combination of codes

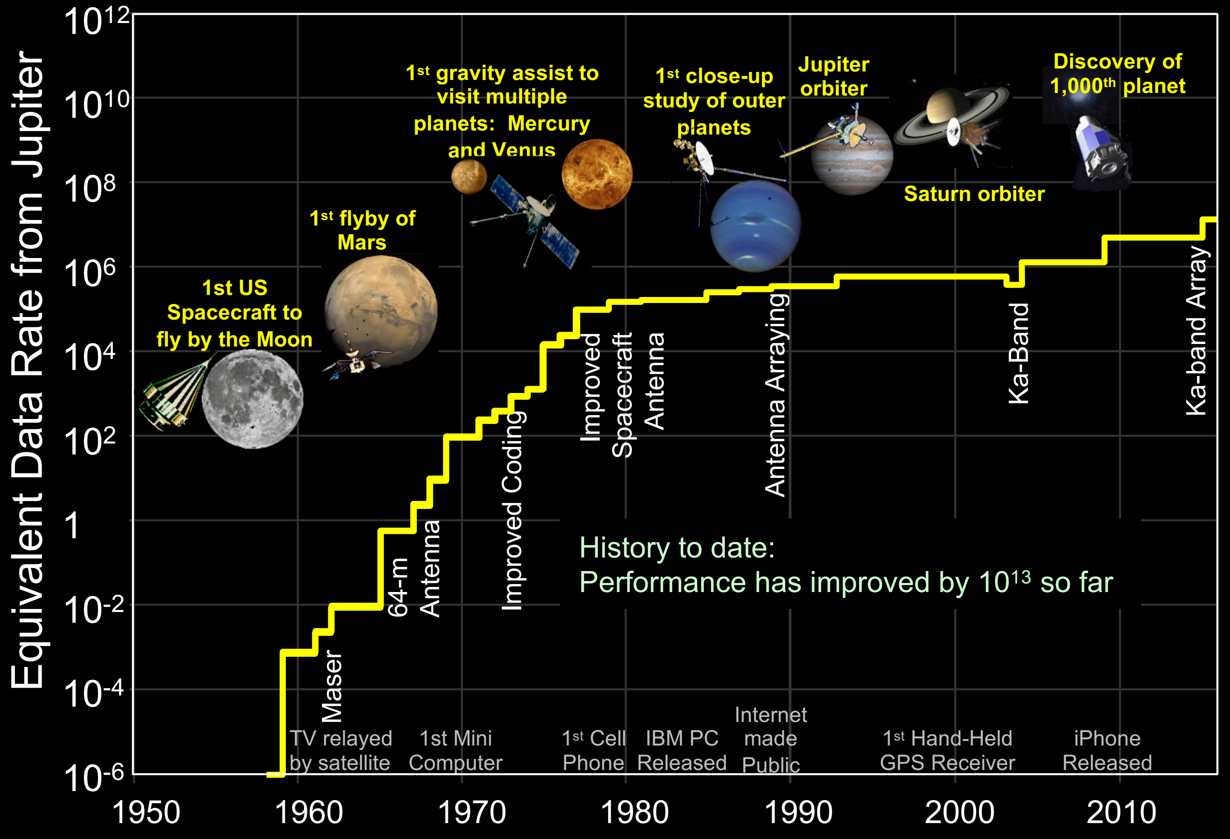
Frame Rejection Rate	Block Size (frame or packet)	Coding and Link Margin
$< 10^{-6}$	8920 bits	Convolutional (r=1/2, k=7), code concatenated with Reed-Solomon (223/255) block code; @ $E_b/N_0 \geq 1.8$dB
$< 10^{-4}$	8920 bits	Rate = 1/3 turbo code; @ $E_b/N_0 \geq 0.4$dB
$< 10^{-5}$	1784 bits	Rate = 1/6 turbo code; @ $E_b/N_0 \geq 0.4$dB
$< 10^{-6}$	1024 bits	Rate = 1/2 low density parity code; @ $E_b/N_0 \geq 2.4$ dB

Example Frame Rejection Rates

Compression – Being stingy with bits

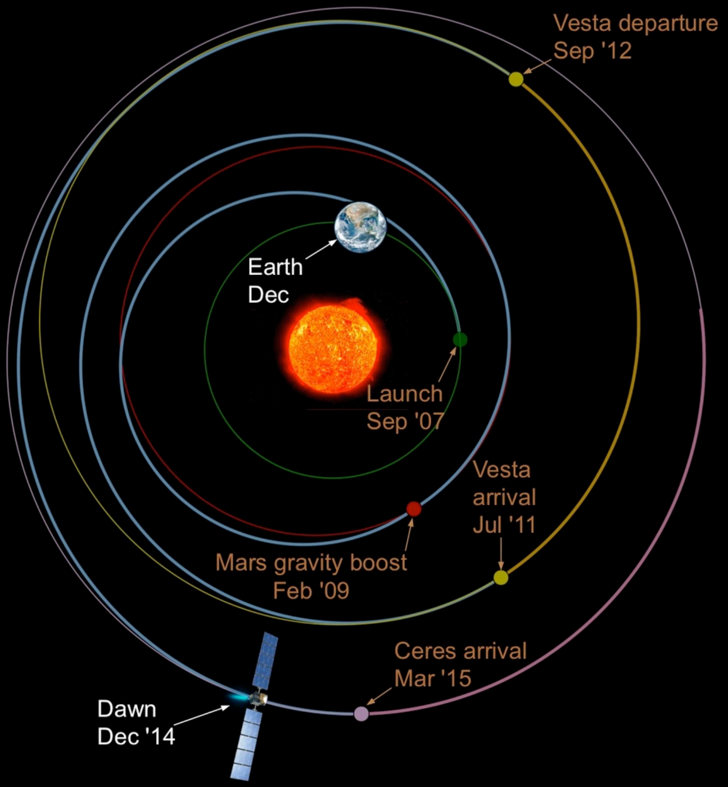
- Data compression is often used by missions
- Images can be compressed 10:1
- Videos and hyperspectral images even more
- Even better: Use data onboard to answer questions and only send the answers!
  - Navigation – where am I now?
  - Locating interesting areas in a scene
  - Onboard science

A History of Improving Communications

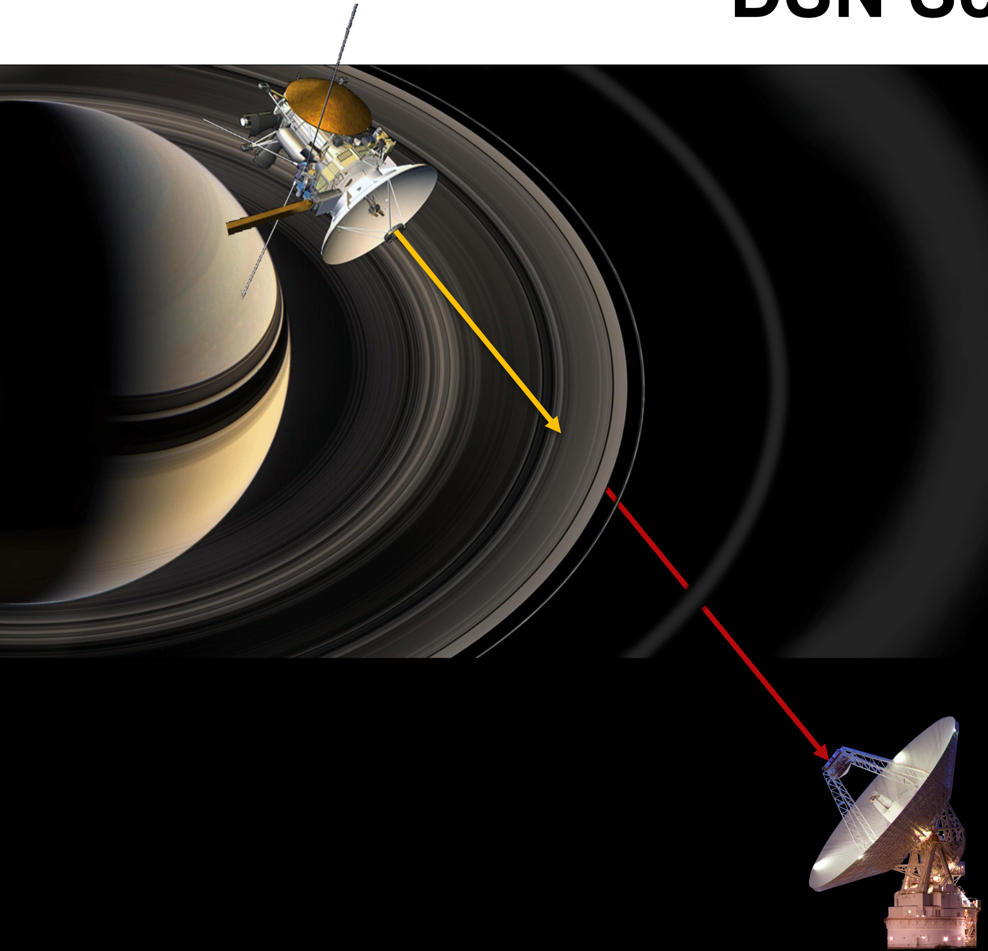


Navigation using the Communications Signal

- There is no GPS in deep space
- Radio signal are the primary observables:
  - Ranging: measurement of the distance to the spacecraft
  - Doppler: measurement of the relative spacecraft motion
  - Delta Differenced One-Way Ranging (ΔDOR): Using multiple ground antennas to measure angle in the plane of the sky the sky
- Plus on-board sensors

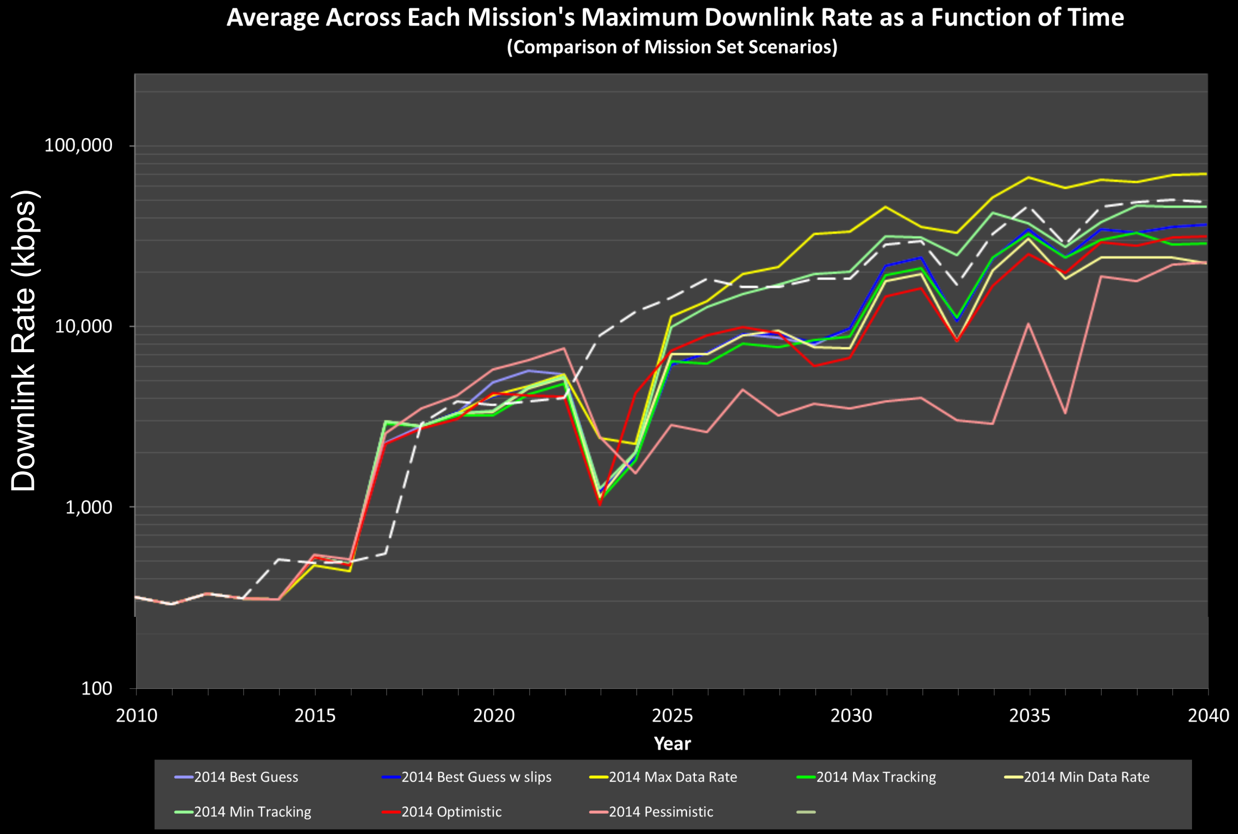


DSN Science



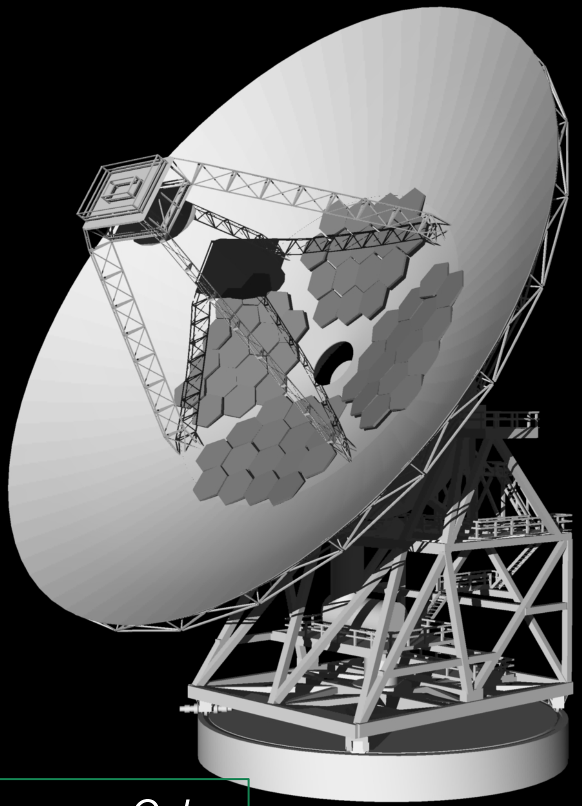
- Measuring perturbations in the link
  - Attenuations
  - Spacecraft wobble
  - Frequency deviation
- We learn things about
  - Rings and particles
  - Atmospheres
  - Interiors of bodies
- We use the DSN as a radar
  - See through atmospheres
  - Study terrain
  - Assess danger from asteroids

Challenge: Future Missions Generate More Data



Optical Communication in the DSN

- We will demonstrate deep space optical communications on the 2022 Psyche mission
- Uses Palomar 200" – but we need an operational capability
- Add small, actuated spherical glass mirrors to 34m DSN antennas to provide an equivalent 8m spherical aperture
- Place a photon-counting optical detector at apex
- More than x100 higher data rates versus radio frequency
- Prototype 2019-2020; Implementation 2021-2023;Testing 2023-2025; Operational system at Goldstone in 2025
- Use separate, much smaller aperture for uplink, reducing requirements on this larger system



Pre-Decisional Information – For Planning and Discussion Purposes Only

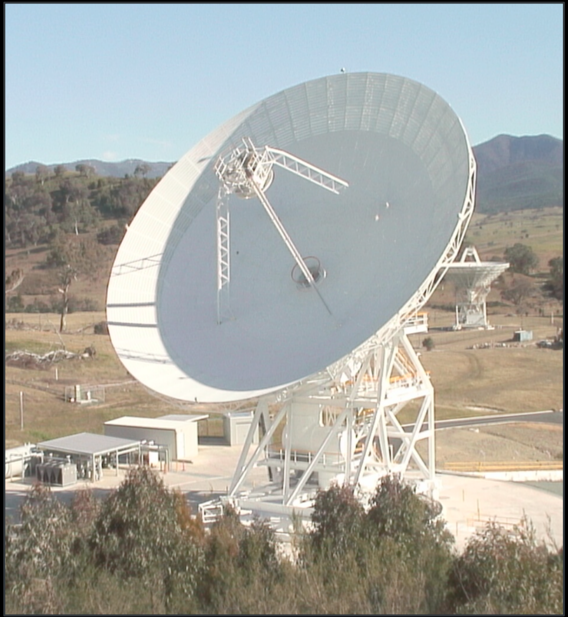
DSN Aperture Enhancement Project (DAEP)

- Add capability to DSN to meet growing need
- Precise construction of a very large instrument with stringent performance parameters and unique electronics
- Construct an array of four, 34-m Beam Waveguide (BWG) Antennas at each of the DSN's communications complexes.
- Can be arrayed to backup 70m capability

Pre-Decisional Information – For Planning and Discussion Purposes Only

DAEP Rollout Plan

DSS-36 Delivered in 2016



DSS-35 Delivered in 2014

- Started in 2009 with construction of 2 new antennas at the Canberra Complex, delivered in 2014 & 2016
- Broke ground at the Madrid Complex in 2016 on 2 antennas currently under construction
- Early stages of development for one at the Goldstone Complex to be delivered in 2024
- Final delivery of this phase of development planned for Canberra in 2026

Madrid Construction Process

Pour Concrete Foundation

Add concrete Walls to Pedestal Structure

Madrid Construction Process

Install Azimuth Track

Construct Steel Base frame

Madrid Construction Process

Complete Base frame

Assemble Reflector

Madrid Construction Process

Reflector Lift

Reflector Placement

Madrid Construction Process

Quadrapod Lift

Panel Installation

DSN Summary

- Global organization for deep space communication research, development, operations and maintenance
- Unique antennas that have stringent pointing, tracking, and stability requirements
- Specially designed electronics
  - Receive weak downlink signals
  - Uplink high power to distant spacecraft
- Mission demand for antenna time
  - Enhancing the network
  - Increasing performance
- Creating Operational & Maintenance Efficiencies

The Deep Space Network

Presents...